International Journal of Electrical and Electronics Engineering Research (IJEEER)
ISSN (P): 2250-155X; ISSN (E): 2278-943X
Vol. 7, Issue 4, Aug 2017, 37-48

CHECKING THE FEASIBILITY OF HYBRID SOLAR PV-BIOMASS POWER PLANT IN RAJASTHAN

PRATEEK MALHOTRA[1] & TARUN NARUKA[2]

[1]*M.Tech Scholar, Department of Electrical Engineering, SKIT, Jaipur, Rajasthan, India*

[2]*Assistant Professor, Department of Electrical Engineering, SKIT, Jaipur, Rajasthan, India*

ABSTRACT

In today's scenario, where the adverse effect of energy scarcity is clearly visible, there is a dire need for sustainable energy sources. Electricity is an essential part of our daily life and we are getting short of it, so we are now moving toward renewable energy. Solar energy is available for limited number of hours and prices of biomass vary widely. Hybridization of solar energy with biomass energy complements each other, both seasonally and diurnally, to overcome their individual drawbacks and result is continuous and uniform supply of electricity. Rajasthan receives solar radiation of 6-7 kWh/m2 according to data taken from NREL (National Renewable Energy Laboratory) and is blessed with bulk surplus quantity of biomass all around. Major biomasses in Rajasthan that are used for generating electricity are Julie Flora, Guar Stalks, Cotton Stalks and Mustard Husk. By Hybrid Solar PV-Biomass plant, operation range can be increased from 06:00 hours to 22:00 hours. The main objective of this paper is to find best configuration of standalone Solar-Biomass energy system in terms of optimum sizing and minimum Total Net Present Cost (NPC) and minimum Cost of Energy (COE).

KEYWORDS: Hybrid, HOMER, NREL, NPC & COE

Received: Jul 05 2017, **Accepted:** Jul 20 2017, **Published:** Jul 26 2017, **Paper Id:** IJEEERAUG20175

Original Article

INTRODUCTION

One of the primary needs for development is reliable and green electricity supply. The use of renewable energy is increasing continuously, to meet the demand. Most importantly energy must be produced in most economical and environmental friendly manner, by utilising all available fuels and solar energy. The provision of electricity through renewable source is financially more attractive as compared to the extension of the grid. There is a growing interest in harnessing renewable energy sources, since they are available in abundance, pollution free and inexhaustible. However renewable energy has some drawbacks such as poor reliability. We cannot depend totally on renewable energy, because solar energy is available for limited number of hours, affected by clouds and biomass such as, crops and their residue depends on weather conditions and their prices vary on a wide scale. These drawbacks of solar and biomass energy can be removed by making the system hybrid [1]. Hybridization of solar with biomass will complement each other, both seasonally and diurnally, and will overcome the drawbacks that they both individually possess [2].

LITERATURE REVIEW

In the past years in HES (Hybrid Energy Systems), various investigations were carried out in the literature, which studies the different aspects of optimization of renewable energy systems, especially solar, wind and biomass energy. [1] Presented a paper on techno economic analysis of HES consisting of Solar PV- Biomass

energy, for a village in Gorakhpur District and concluded that, hybrid system is a viable green technology source for rural electrification. [3] Formulated MILP (Mixed Integer Linear Programming) model, for optimization of hybrid Solar PV-Biomass plant in Iskandar Malaysia (IM) and concluded that, it is indeed feasible for IM to rely on HES, to satisfy average daily load of 16,900kwh/day. [4] Proposed a paper on optimization of biomass based Solar PV Plant, for off grid application, using Harmony Search Algorithm and proved that, hybrid plant is better than PV only plant, for problems of agricultural well electricity demand in Iran. [5] Presented a paper on Economic and environmental analysis of biomass-solar hybrid system, for textile industry in Tamil Nadu, with the goal of minimizing the cost and greenhouse gas emission, using HOMER Pro Software. Paper concludes that, from economic point of view, grid only system costs less than HES in present scenario, but with successful technological upgrades and decreased prices of PV panels, HES will become best sustainable energy option in India. [6] Presented a paper on Sustainable rural development by Solar/Biomass Hybrid Renewable energy system, using Air Gap Membrane Distillation (AGMD), using HOMER Pro Software and concluded that, this hybrid system costs less than the standard cost. [7] Analysed model of Hybrid Distributed Generation System for DC Nano-GRID, in South Africa using HOMER Pro Software and concluded that, the proposed system is feasible and will deliver reliable power with lower COE, and with a payback period of 4 years. [8] This paper reviewed different computer tools that can be used to analyse the integration of renewable source of energy. 37 tools including HOMER were analysed. The paper concludes that, there is no energy tool that covers all the issues related to integrating renewable energy. [9] Presented a paper on Solar- Biomass Hybrid System for village near Barisal city in Bangladesh, using HOMER Pro Software and concluded that, with abundant renewable resources in Bangladesh the COE of hybrid system comes out to be less than the COE of the Grid. [10] Presented a paper on simulation and performance analysis of 110kw grid connected Solar PV plant for residential hostel building at MANIT, Bhopal and compared four types of PV Technologies- Crystalline Silicon (c-si),Amorphous Silicon (a-si), Cadmium Telluride (CdTe) and Copper Indium Selenide (CIS). The paper concludes that PR of these PV systems varies from 70% to 88% and (a-si) and (CdTe) PV systems have their PRs higher than 75%. [11] Presented a paper on biomass energy resources (grass, crops, fruits, vegetables etc.), energy potential in India and conversion of energy through various thermo- chemical and biochemical techniques. The paper concludes that in India huge Potential exists for exploration of available biomass to convert it into energy.

STUDY LOCATION

Jaiprakashpura is a small village in Chaksu district, merely 52 KM from the state capital of Rajasthan.

Table 1: Study Location Description

Location	Jaiprakashpura, Rajasthan, 303901, India
Latitude	26 degrees 33.15 minutes North
Longitude	76 degrees 1.48 minutes East
Time Zone	Asia/Kolkata

Potential of Solar Energy

Rajasthan is blessed with abundant solar energy and if harnessed efficiently, the state is capable of producing electricity on a large scale [2]. Figure 1 represents daily radiation data and clearness index of the proposed area.

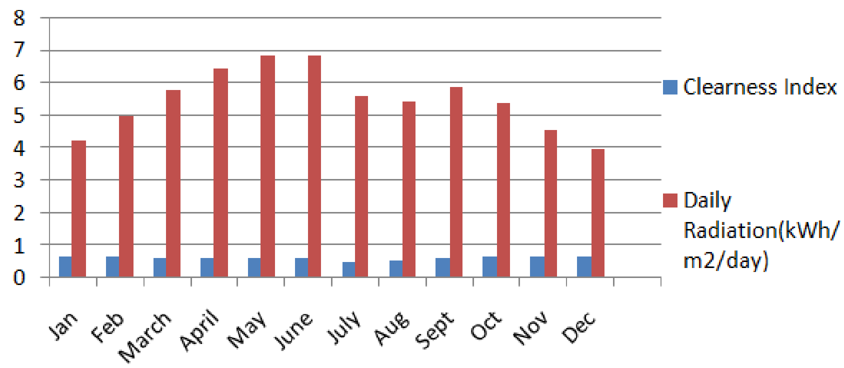

Figure 1: Solar Radiation and Clearness Index Data of Jaiprakashpura [14]

Potential of Biomass Energy

Biomass is the oldest source of energy known to humans. The term biomass encompasses a large variety of materials, including wood from various resources, agricultural residues and animal and human waste [3]. In comparison with many renewable energy options, biomass has the merit of dispatch ability. This means that biomass energy is controllable and available when it is required. However, the disadvantage of such system is that the fuel needs to be procured, delivered, stored and paid for. One of the technologies for the extraction of energy from biomass resource is anaerobic digestion. Anaerobic digestion is a series of biological processes in which micro organisms break down biodegradable materials such as live stock manure, municipal waste water solids, food waste, fats, oils and various other organic wastes in the absence of oxygen. One of the end products is biogas which is used to generate electricity and heat. Biogas produced in anaerobic digesters consists of methane (45–75%), carbon dioxide (25–55%) and trace levels of other gases. For conversion of bio-methane into heat and electricity, a biogas engine–generator is used[4]. Table 2 represents biomass potential data in Rajasthan.

Table 2: Potential of Biomass in Rajasthan

Major Biomass Consumed by Power Plant	**Mustard Stalks and Husk Guar Stalks Prosopis Juliflora Wood Cotton Stalks**
Estimated average price of all biomass in 2017 (excluding storage and feeding cost) Rs./ton	Rs. 2797
Average escalation of all major biomass cost	10.50%
Average storage and feeding cost (Rs./ton)	Rs. 220
Biomass storage and handling cost	2%

It is found that, the biomass generated from agricultural activity is 5,26,89,79 tons/year, about 4,78,13,642 tons/year (90.75 %) consumed by local people for fodder, manure, fuel for thermal energy consuming industries, biomass power plants, brick kiln, etc. and about only 48,76,155 Tons/year(9.25%) is available as surplus[15].

Load Profile

There are 38 households in the village out of which 26 are electrified[20]. Each house comprises of 2 fans(60W each), 4 led bulbs(7W each), TV (60W), regular appliances. 5 street lights of 15W each and load of village school is also considered. So average load considered in this paper is 190 kWh/day with peak load of 11.5 kWand 6 kWh/day with peak

load of 0.75 kW for school and street lights. Figure 2 represents the daily load demand of the village houses. Figure 3 represents the daily load demand of the street light (0-5 and 19-23 hours) and Figure 4 represents daily load demand of the school (9-15 hours).

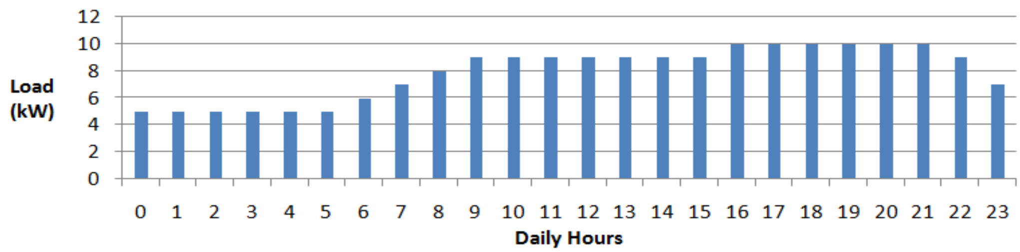

Figure 2: Daily Load Demand of Village Houses

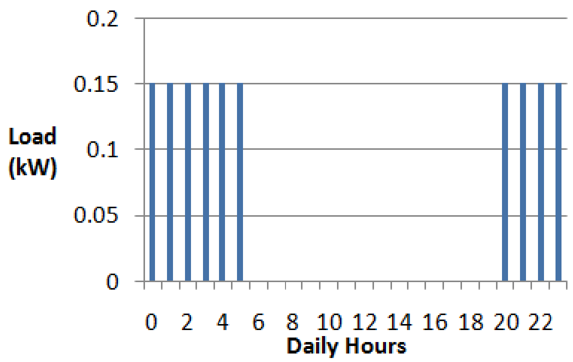

Figure 3: Daily Load Demand of Street Lights

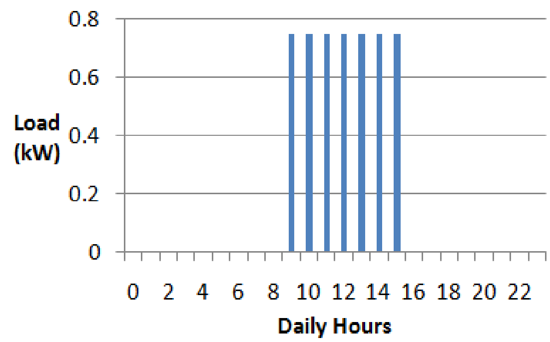

Figure 4: Daily Load Demand of Village School

HOMER PRO SOFTWARE

For the past few years much research has been conducted regarding standalone and grid-connected Renewable Energy (RE) sources, all over the world. The HOMER tool has been used to analyze a hybrid electric supply system (hydro/PV/wind/ biomass) and to find the optimum sizing of components for a diesel-based RE system [5]. The name HOMER is an abbreviation of Hybrid Optimization Model for Electrical Renewable and it is developed by U.S. National Renewable Energy Laboratory (NREL). HOMER Pro allows simulation of various combinations of Solar PV modules, Wind turbines, and Biomass based generators[12].Working effectively with HOMER requires understanding of its three core capabilities[19] –

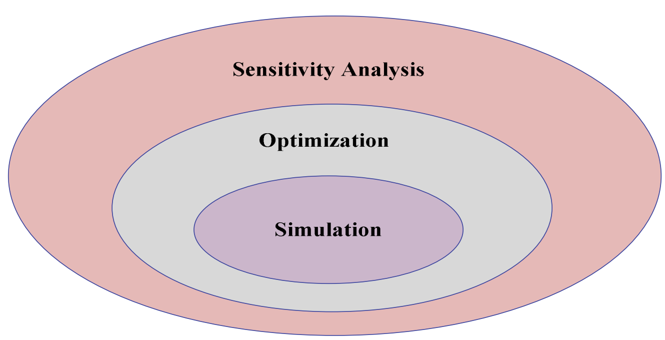

Figure 5: Core Capabilities of HOMER

Simulation: At its core, HOMER is a simulation model. HOMER simulates a viable system for all possible combinations of the equipment that is to be considered. Depending on the problem, HOMER may simulate hundreds or even thousands of systems.

Optimization: The optimization step follows all simulations. HOMER sorts all the simulated systems and filter them according to criteria define defined by us, so that we can see the best possible fits.

Sensitivity analysis: This is an optional step that HOMER allows to model the impact of variables that are beyond our control, such as wind speed, fuel costs, etc., and see how the optimal system changes with these variations.

Economic Modeling

To represent the life cycle cost of the system, HOMER uses total Net Present Cost (NPC). The total NPC consists of all the costs and revenue that occurs within the project lifetime. The NPC includes the cost of initial construction, component replacement and fuel. For calculation of NPC, HOMER uses the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,R_{proj})}$$

Where,

$C_{ann,tot}$ is the total annualized cost,

i is the annual interest rate (the discount rate),

CRF is the Capital Recovery Factor.

CRF is given by the equation:

$$\mathrm{CRF}(i,N) = \frac{i(1+i)^N}{(1+i)^N-1}$$

Where,

i is the annual interest rate,

N is the number of years.

For calculation of COE, HOMER uses the following equation:

$$\mathrm{COE} = \frac{C_{ann,tot}}{E_{prim}+E_{def}+E_{grid,sales}}$$

where,

$C_{ann,tot}$ is the total annualized cost,

E_{prim} and E_{def} are the total amount of primary and deferrable load that the system serves per year, $E_{grid,sales}$ is the amount of energy sold to the grid per year[23].

MODELING Of HYBRID SOLAR PV-BIOMASS PLANT

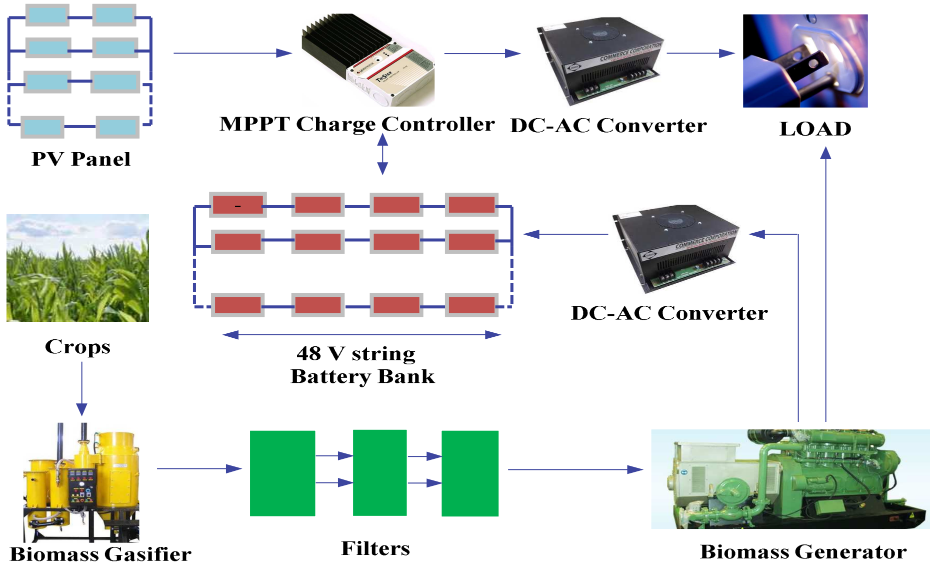

Figure 6 : Hybrid Solar PV-Biomass Plant

Both Solar Energy and Biomass Energy have their individual strengths and weaknesses. Solar energy requires very less maintenance but is limited only for 5-6 hours per day on an average. Biomass energy has an advantage of dispatch ability but biomass prices vary on a wide scale every year. Figure shows Solar PV-Biomass Hybrid power plant which will enhance the potential of the plant by balancing their individual strengths and weaknesses.

Solar PV Panel

It converts sun's rays into electricity by exciting electrons in silicon cells using the photons of light from sun. The power output of the Solar PV panel is given by[13]-

$$P_{PV\ out} = P_{NPV} \times (\frac{G}{G_{ref}}) \times [1 + K_T(T_C - T_{ref})]$$

Where,

$P_{PV\ out}$ = Output power from the PV cell;

P_{NPV} = Rated power at the reference conditions;

G = Solar radiation (W/m^2);

G_{ref} = Solar radiation at reference conditions (G_{ref}= 1000W/m^2);

T_{ref} = Cell temperature at reference conditions ($T_{ref} = 25$□);

K_T = Temperature coefficient of the maximum power ($K_T = -3.7 \times 10^{-3}(1/$□$)$) for mono and polycrystalline Si.

The cell temperature T_C is given by

$T_C = T_{amb} + (0.0256 \times G)$

Where,

T_{amb} is the ambient temperature.

Practically the Performance Ratio (PR) of the solar panel varies from 70% to 88%[10]. Slope angle for the panel is taken as 26.55 degrees. In this paper, the capital cost and replacement cost of PV Panel is taken as 60,000 Rs/kW and 40,000 Rs/kW including cost of MPPT charge controller and mounting structure.

Battery Bank

For Solar plant lead acid deep-cycle storage batteries are used for storing the energy generated by PV panels for providing backup to the system when sun is not present. The Storage Capacity ($C_{W\square}$) is calculated using

$$C_{W\square} = (E_L \times AD)\eta_{inv} \times \eta_b \times DOD$$

Where,

E_L = Total energy demand;

AD = Daily autonomy;

η_{inv} = Inverter efficiency;

η_b = Battery efficiency.

DOD = Depth of Discharge[13].

DOD is the complement of State of Charge (SOC**).** Itdescribes the degree to which a battery is emptied relative to its total capacity.This affects the length of the battery's operational life, as well as the total number of kilowatt-hours it will be able to store over its lifetime. DOD in this paper is taken as 50%. If a lead-acid battery is discharged 100% every time its electrolyte will quickly degrade compared to if it were only discharged to a maximum of 50%. In this paper, the capital cost and replacement cost of 1 kWh 12V 100 Ah battery is taken as 9000 Rs.

MPPT Charge Controller

Maximum Power Point Tracker (MPPT) is a kind of charge controller that utilizes the solar panel power to its maximum potential. The MPPT fools the panels by fiving output with different voltage and current which will allow more power to go into the batteries [16]. Output voltage and current from the solar panel is monitored by MPPT and operating point that will deliver that maximum amount of power to the batteries will be determined. MPPT can accurately track the always-changing operating point where the power is at its maximum, thus the efficiency of the solar cell will be increased[17]. Many algorithms have been developed for tracking maximum power point of a PV generator such as Perturb and Observe (P&O), Incremental Conductance, and fuzzy logic based tracking techniques. These algorithms vary in effectiveness, complexity, convergence speed, sensors and cost[18].

Power Converter

HES that contains both AC and DC elements requires a converter. It acts as both rectifier and inverter accordingly. In this paper, capital cost and replacement cost of power converter is taken as 7,000 Rs.

Major Biomass in Rajasthan

Biomass dispatch ability depends on the seasonality. PropisJuliflora Wood grows throughout the year and also grows on wasteland, thus suits well for Biomass Energy production.

Gasification

Gasification means the conversion of biomass into mixture of combustible gasses called producer gas by partial oxidation of biomass at high temperatures of about 800-900□. The producer gas (with low calorific value) can be directly burned or can be used as a fuel for gas engines[21]. The system consists of updraft or downdraft gasifier[22], gas cleaning filters, and an engine that generates electricity from producer gas. In this paper, cost of biomass generator is considered to be 96000 Rs./kW.

IMPLEMENTATION ON HOMER PRO SOFTWARE

Model of Hybrid System

Figure 7 represents a schematic diagram of Hybrid Solar PV-Biomass-Battery Power Plant. As indicated, scaled annual energy consumption is 190 kWh/day with peak load of 11.58 kW for village houses and 6 kWh/day with peak load of 0.75 kW for school and street lights. PV is connected on the DC bus while Biomass Generator is connected to the AC bus and converter acts as both rectifier and inverter. Whenever battery gets discharged below DOD i.e. 50% and there is no sufficient energy from PV then the battery will be charged from Biomass Generator through rectifier.[Figure 7]

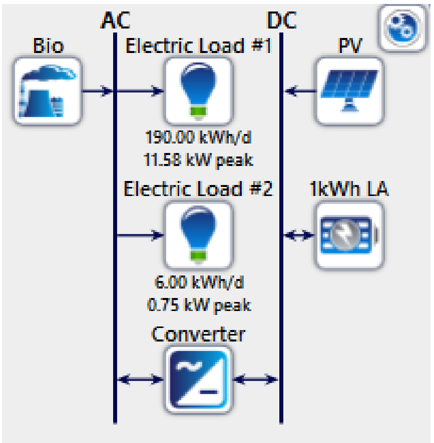

Figure 7: Model of Hybrid System

Optimization Results

HOMER software simulates every possible system configuration and sorts the feasible ones and arrange them in decreasing order of NPC. Figure 8 represents optimization results and the Optimal System comprises of 4.75 kW solar array, 9 kW biomass generator, 20 lead-acid batteries and 6.9 kW converter. NPC of the system is 11.2M Rs. and COE is 12.15 Rs. And Table 3 represents NPC of the hybrid system.

Architecture				Cost				System	Bio		PV
PV (kW)	Bio (kW)	1kWh LA	Converter (kW)	COE (₹)	NPC (₹)	Operating cost (₹)	Initial capital (₹)	Elec Prod (kWh/yr)	Production (kWh)	Fuel (kg)	Production (kWh)
4.75	9.00	20	6.90	₹12.15	₹11.2M	₹762,739	₹1.38M	72557.22	68,946	208	3,611
5.28	9.00	20	7.03	₹12.17	₹11.3M	₹761,660	₹1.41M	72546.59	68,860	208	3,686
5.18	9.00	32	6.93	₹12.28	₹11.4M	₹761,626	₹1.51M	72548.55	68,876	208	3,673
4.87	9.00	36	7.24	₹12.34	₹11.4M	₹764,195	₹1.53M	72554.79	68,926	208	3,629
4.98	9.00	44	6.43	₹12.47	₹11.5M	₹768,149	₹1.60M	72552.39	68,907	208	3,646

Figure 8: Optimization Results

Table 3: Net Present Cost of the Optimal System

Component(Rs.)	Capital (Rs.)	Replacement (Rs.)	Fuel (Rs.)	Salvage (Rs.)	Total(Rs.)
PV system	285,006	0	0	0	285,006
Biogas Genset	864,000	2,352,792	7,268,851	-5,390	10,480,253
1 kWh Lead Acid Battery	180,000	250,416	0	-22,976	407,439
Converter	48,268	20,479	0	-3,854	64,893
System	1,377,274	2,623,687	7,268,851	-32,221	11,237,591

Simulation Result

Figure 9 represents plot of System Load, PV Output, Biomass Output and Battery State of Charge with zero percent unmet load. If battery state of charge gets below 50 % and there is not enough solar potential then the battery is charged through biomass generator to maintain battery SOS above 50 %.

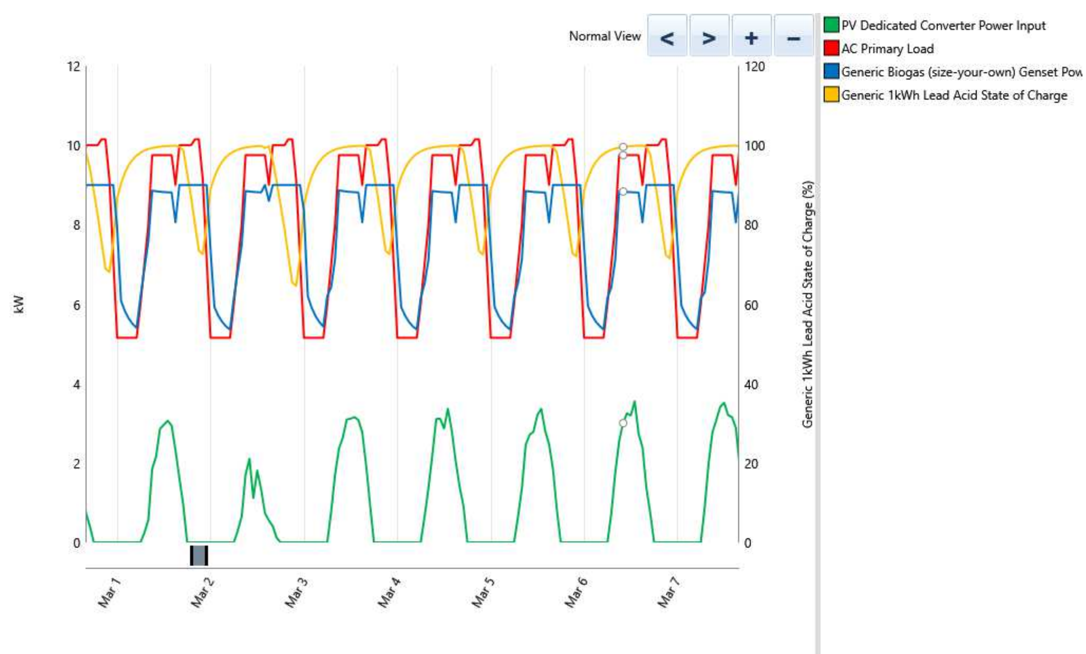

Figure 9: Plotting of System Load, PV Output, Biomass Output and Battery State of Charge

Sensitivity Analysis

Scaled Average Load(kWh/day) and Biomass Price(Rs./ton) are taken as sensitivity variables.

Table 4: Sensitivity Variables

Scaled Average Load(kWh/day)	40	60	80	140	190	220
Biomass Price(Rs./ton)	2500	2700	3000	3200		

The Optimal System Type (OST) Graph gives the highest-level view of the sensitivity results. Different system configurations such as Bio, Bio/Battery, Bio/PV, Bio/PV/Battery are obtained in OST graph. Sensitivity analysis in Figure 10 represents that after load of 88 kWh/day Bio/PV/Battery system has the least NPC at all prices of Biomass(2500 Rs. to 3200 Rs.). Diamonds represent NPC for every sensitivity case. For our case where, average scaled load is 190 kWh/day and biomass price is 2700 Rs. PV/Bio/Battery system is most economical.

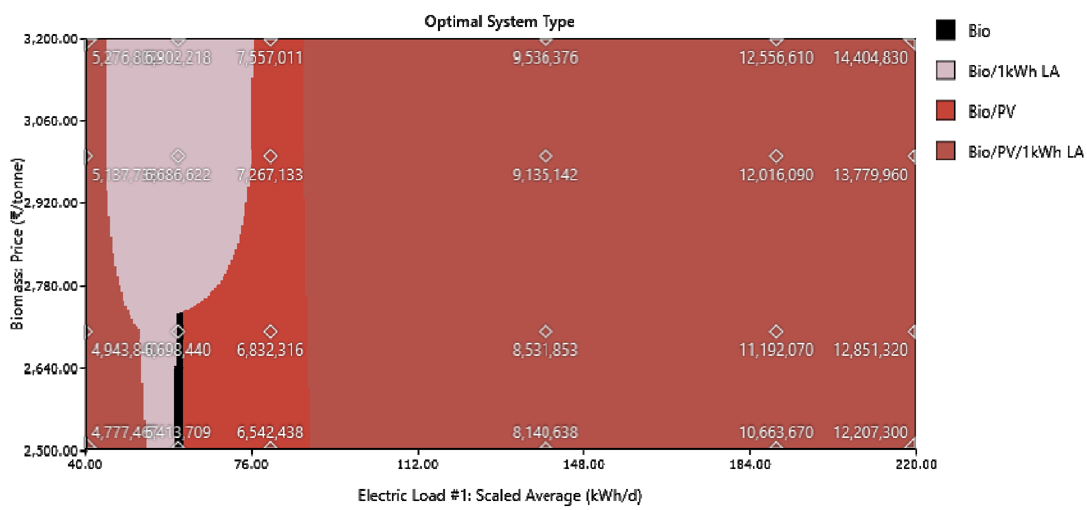

Figure 10: Sensitivity Analysis by Optimal System Type Graph

CONCLUSIONS

In this paper, Hybrid Solar PV/Biomass Plant is modeled, simulated and optimized for Jaiprakashpura village in Rajasthan. HOMER Pro software is used in designing and modeling the optimal system. To serve the daily load requirement of the village the optimal system consists of 4.75 kW PV, 9 kW Biomass generator, 20 Lead-Acid batteries (12V,100Ah) and 6.90 kW Converter. NPC and COE for the optimal system are 11,237,591 Rs. and 12.15 Rs. It is clearly seen that the system is feasible and can deliver reliable power at lower rates with zero unmet load.

REFERENCES

1. *Sachchidanand Pandey, DevendraVashist. Techno Economic Analysis of Hybrid Solar PV and Biomass System for Rural Electrification, IRJET Volume 3, Issue 06, June 2016.*
2. *T.Srinivas, B.V Reddy. Hybrid Solar-Biomass power plant without energy storage. Case studies in thermal engineering, Case Studies in Thermal Engineering, 2(2014) 75-81.*
3. *W.S Ho, H. Hashim, J.S. Lim. Integrated biomass and solar town concept for a smart eco village in Iskandar Malaysia(IM), Renewable Energy, 69(2014) 190-201.*
4. *Ali Heydari, AlirezaAskarzadeh. Optimization of a biomass-based photovoltaic power plant for an off-grid application subject to loss of power supply probability concept, Applied Energy, 165(2016) 601-611.*
5. *MahadevanMahalaxmi, SalaiLatha. An economic and environmental analysis of biomass-solar hybrid system for the textile*

industry in India, Turkish Journal of Electrical Engineering and Computer Sciences, (2015)1-13.

6. *IfegwuEziyi, AnjaneyuluKrothapalli. Sustainable rural development: solar/biomass hybrid renewable energy system, Energy Procedia, 57(2014) 1492-1501.*
7. *Ester Hamatwi, Inno Davidson, Ganesh K. Venayagamoorthy. Model of a hybrid distribution generation system for a dc nano-grid,IEEE Conference Paper March 2016.*
8. *D. Conolly, H. Lund, B.V. Mathiesen, M.Leahy. A review of computer tools for analyzing the integration of renewable energy into various energy systems, Applied Energy(2009).*
9. *Md. Raju Ahmed, SubirRanjanHazra, Md. MustafizurRehman, RowsanJahanBhuiyan. "Solar-biomass hybrid system; proposal for rural electrification in Bangladesh", ELELIJ, Vol 4, No1, Feb 2015.*
10. *Akash Kumar Shukla, K. Sudhakar,PrashantBaredar. Simulation and performance analysis of 110 kWp grid connected photovoltaic system for residential building in India: A comparative analysis of various PV technology, Energy Reports, 2(2016) 82-88.*
11. *Anil Kumar, Nitin Kumar, PrashantBaredar, AshishShukla. A review on biomass energy resources, potential, conversion and policy in India, Renewable and Sustainable Energy Reviews, 45(2015) 530-539.*
12. *Anand Singh, PrashantBaredar, Bhupendra Gupta. Computational simulation and optimization of solar, fuel cell, and biomass hybrid energy system using HOMER Pro software, Procedia Engineering 127(2015) 743-750.*
13. *Anand Singh, PrashantBaredar. Techno-economic assessment of a solar PV, fuel cell and biomass gasifier hybrid energy system, Energy Reports, 2(2016) 254-260.*
14. *PVWatt Calculator India, National Renewable Energy Laboratory(NREL), (http://pvwatts.nrel.gov/india/)*
15. *Biomass Fuel Supply Study 2017, Rajasthan Renewable Energy Corporation Limited(RRECL), (http://energy.rajasthan.gov.in/content/raj/energydepartment/rrecl/en/activities/biomass.html)*
16. *Gergaud O, Multon B, Ben Ahmed H. Analysis and experimental validation of various photovoltaic system models, 7th International Electrimacs Congress, Montreal, Canada, 2002, 1-6.*
17. *AbdelazizTalha. MPPT techniques for PV Systems, Conference Paper May 2013.*
18. *Esram T, Chapman P.L. "Comparison of photovoltaic array maximum power point tracking techniques". IEEE Trans. Energy Conversion, 2007. 22, 439-449.*
19. *HOMER Pro Version 3.7 User Manual, (www.homerenergy.com/pdf/HOMERHelpManual.pdf)*
20. *Know your village, Jaiprakashpura, (www.garv.gov.in)*
21. *Peter McKendry, Energy production from biomass(part 2): conversion technologies, Bio resource Technology, 83(2002) 47-54.*
22. *Peter McKendry, Energy production from biomass(part 3): gasification technologies, Bio resource Technology, 83(2002) 55-63.*
23. *HOMER Pro Version 3.7 User Manual.(www.homerenergy.com/pdf/HOMERHelpManual.pdf)*